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HIRAS IMAGES OF FOSSIL DUST SHELLS AROUND AGB STARS

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ABSTRACT We present high resolution HIRAS 60 and 100 μm images of AGB stars surrounded by fossil dust shells. Resolving the extended emission of the circumstellar dust allows a determination of the mass loss history of the star. We show that the geometry of the 60 μm emission surrounding HR 3126 agrees well with that of the optical reflection nebula. The emission around the carbon star U Hya is resolved into a central point source and a ring of dust, and the mass loss rate in the detached shell is 70 times higher than the current mass loss rate.

INTRODUCTION

Stars on the Asymptotic Giant Branch (AGB) are known for their very high mass loss rates, with values that range between about 10^{-7} and $10^{-4} M_{\odot} \text{ yr}^{-1}$ and with outflow velocities of 5-30 km s^{-1} . In these dense, cool outflows dust can easily condense; AGB stars are often highly reddened by circumstellar dust and radiate their energy mainly in the (far)-infrared, and therefore can be studied best at such wavelengths.

The IRAS satellite has detected many AGB stars throughout our Galaxy and even in the Magellanic Clouds. These observations show that there is a large range in optical depth of the dust shells surrounding these stars, i.e. there is a large range in mass loss rates. A matter of debate is however if and how the mass loss changes with time for AGB stars of different chemical composition. The difficulty is that for most AGB stars the distance and thus the luminosity is not known, and therefore the effects of mass and luminosity on the mass loss rate cannot be disentangled. Knowledge of mass loss rates as a function of time is paramount for a better understanding of AGB evolution because mass loss determines evolutionary timescales for these stars.

Studies of the distribution of C and M stars in the IRAS color-color diagram led to the conclusion that mass loss in C stars, and to some extent also in M stars is not constant but varies strongly on relatively short timescales (e.g.,

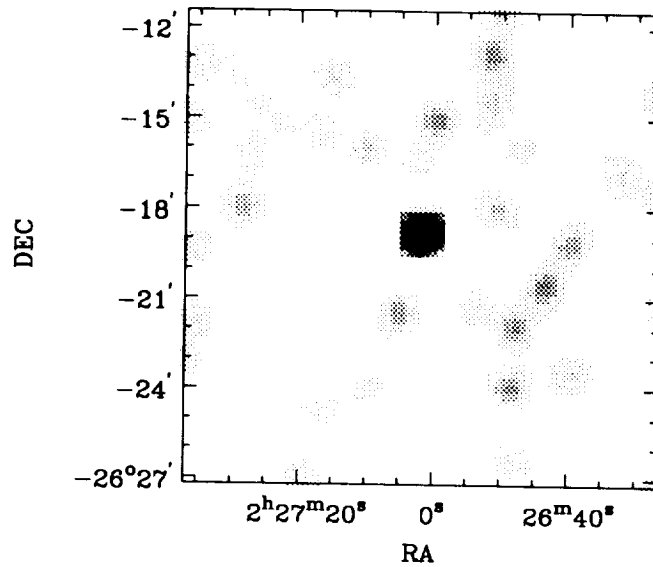


FIGURE 1 Grey-scale image of the $60\ \mu\text{m}$ emission of R For. The source has no $60\ \mu\text{m}$ excess and indeed is a point source. Image size is $16' \times 16''$ and pixel size is $15''$

Willems & de Jong 1986,1988; Chan & Kwok 1988; Zijlstra et al., 1992). This conclusion is based on the fact that many C stars and some M stars show a large 60 and $100\ \mu\text{m}$ excess due to a cool dust shell at large distance from the star. This dust shell probably was ejected some time ago when the mass loss rate was much higher than at present. Indeed some nearby C stars such as U Hydrae are associated with *IRAS Small Scale Structure Catalog* at 60 and $100\ \mu\text{m}$ suggesting the presence of a fossil shell of dust.

Independent confirmation of the presence of fossil shells around AGB stars came from observations of extended CO emission in S Sct, U Ant and TT Cyg (Olofsson et al. 1990), clearly demonstrating the presence of a detached shell of molecular gas expanding at velocities between 13 and $22\ \text{km s}^{-1}$. The dust in this shell very likely causes the observed 60 and $100\ \mu\text{m}$ excess.

HIRAS IMAGES OF FOSSIL DUST SHELLS

We have used the Groningen HIRAS system to produce high resolution 60 and $100\ \mu\text{m}$ images of the extended emission around about 30 well studied AGB stars. For a description of the system we refer to Bontekoe et al. (1993). We used as input list the results obtained by Young et al. (1993) who used one dimensional co-adds of IRAS scans to determine whether or not the source is extended. In addition, we used the list of Loup (1991) containing AGB stars with high quality detections in the four IRAS bands. Here we report on the results obtained for three objects, R For, HR 3126 and U Hya.

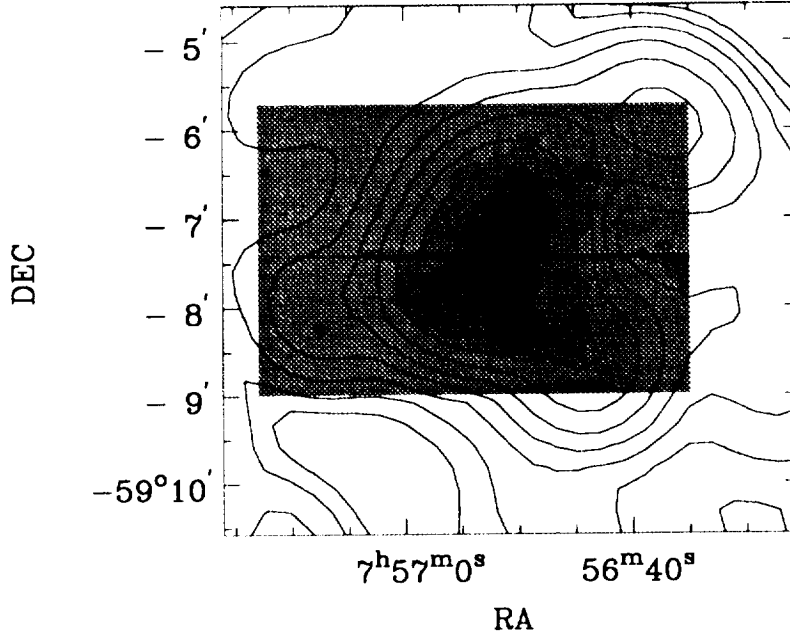


FIGURE 2 Grey-scale image of the continuum emission in the I-band of the reflection nebula around HR 3126. Superposed are the 60 μm contours, that closely follow the optical image

R FOR

Figure 1 gives the 60 μm image of the carbon star R For. The star has no 60 μm excess as deduced from the IRAS broad-band photometry (Loup 1991) and also the star is not associated with an extended source. The region around R For is relatively free of cirrus. As can be seen in Figure 1, the 60 μm image essentially shows a point source without any evidence for extended emission, which is as expected.

HR 3126

The MO III star HR 3126 is a peculiar M giant whose evolutionary status is not well understood. It is surrounded by a reflection nebula (IC 2220) which has a filamentary structure. Deep images taken by Dachs & Isserstedt (1973) and Witt & Rogers (1991) show the nebula is bipolar with filaments suggesting the geometry may be caused by magnetic fields. A recent detailed CO map by Nyman (1993) shows that the CO emission is also bipolar. A study of the IR spectrum of HR 3126 by Chiar et al. (1993) shows that the dust is oxygen-rich and has a very wide temperature distribution.

In Figure 2 we present a superposition of the I-band image published by Witt & Rogers (1991) (halftone) and the 60 μm HIRAS image (contours). The spikes in the image are due to the central star which is overexposed. The 60 μm emission is clearly extended and follows the emission of the reflection nebula, which proves that the dust radiating at 60 μm is also responsible for the optical reflection. The fact that the nebula is extended at 60 μm in combination with

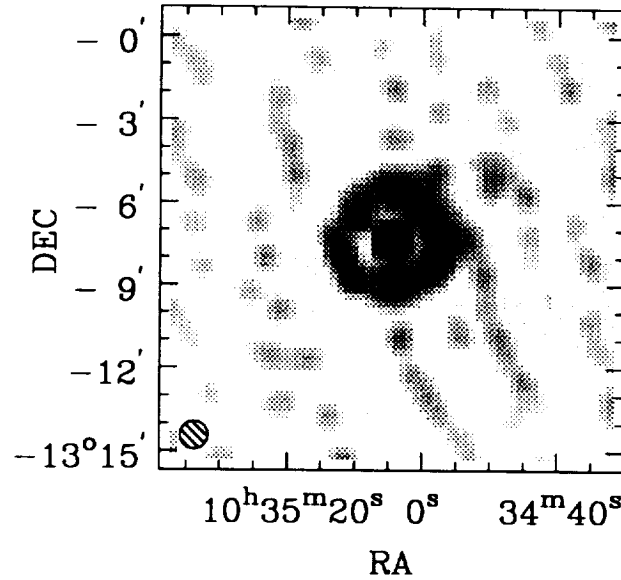


FIGURE 3 Half-tone image of the maximum entropy solution to the $60\ \mu\text{m}$ brightness distribution for U Hydrae. Dimension of the image is $16'\times 16'$ and the pixel size is $15''$. The resolution at $60\ \mu\text{m}$ is $1.0'$.

the geometry strongly suggests that the mass loss of HR 3126 was much larger in the (recent) past than at present ($2\text{--}4\ 10^{-7}\ M_{\odot}\ \text{yr}^{-1}$, Reimers 1977).

U HYDRAE

The carbon star U Hya is one of the brightest AGB stars in the visual, and therefore probably also one of the nearest carbon stars. The IRAS data on U Hya reveal the presence of a Small Extended Source as well as a point source. The star has CO (1-0) millimeter emission from which a present-day mass loss rate of $2\ 10^{-7}\ M_{\odot}\ \text{yr}^{-1}$ is derived (Kastner 1990). In Figures 3 and 4 we present the 60 and $100\ \mu\text{m}$ images of U Hya. At $60\ \mu\text{m}$ the source is clearly resolved into a central point source and a detached ring of emission with a radius of about $1.75'$. At $100\ \mu\text{m}$ the reduced resolution of HIRAS (estimated to be $1.7'$) does not allow the source to be resolved into a central star and detached ring. The overall distribution of intensity is consistent with that seen at $60\ \mu\text{m}$.

We have estimated the age of the shell using a distance to U Hya of $350\ \text{pc}$ and an expansion velocity of $15\ \text{km}\ \text{s}^{-1}$, and find $12,000$ years since the shell was ejected. With a simple optically thin dust model we find a mass loss rate of $1.4\ 10^{-5}\ M_{\odot}\ \text{yr}^{-1}$, which is a factor 70 higher than the present-day mass loss rate. Clearly the mass loss of carbon stars on the AGB is not constant but varies considerably on timescales of (at least) 10^4 years. Such timescales are in the same order of magnitude as the thermal pulse timescale for evolved AGB stars (Boothroyd & Sackmann 1988). A more detailed description will appear elsewhere (Waters et al., 1993).

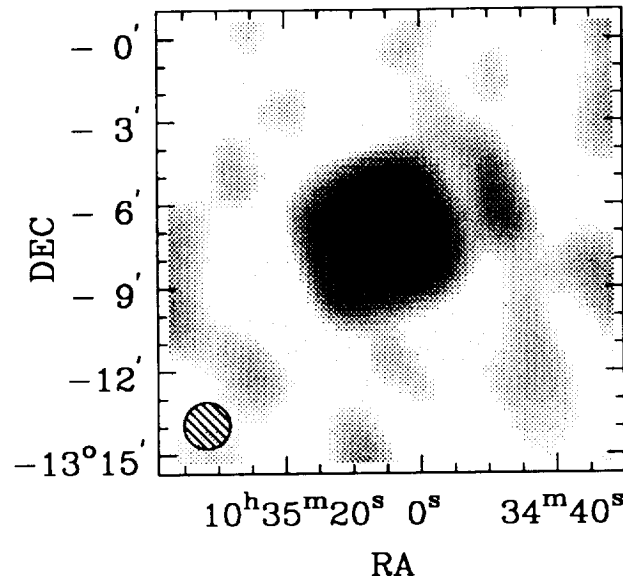


FIGURE 4 Same as Figure 3 but at $100\ \mu\text{m}$. The resolution of $1.7''$ does not allow the source to be resolved into a central star and ring.

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